REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
09/30/07	Final Report	08/01/07-09/15/07

4. TITLE AND SUBTITLE
Army SBIR, Interim Funding Final Report

5a. CONTRACT NUMBER
W911NF-07-C-0022

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Lumidigm, Inc.

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release: distribution unlimited unclassified

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPONE NUMBER *(Include area code)*
Unclassified	Unclassified	Unclassified			505-272-7084

Rob Rowe

Army SBIR, Interim Funding
Final Report

Work conducted under the interim funding for this program comprised three parts:

1. Conduct a significantly larger multiperson study than performed in Phase I and use the resulting data to determine system performance and optimize algorithms
2. Develop a means to automatically localize and segment the fingertips prior to extraction and matching of fingerprint characteristics.
3. Develop a means to process the entire hand image to produce a composite image that emphasizes Level II biometric characteristics (e.g. ridges, cores deltas, etc).

Reports of the first two activities were previously submitted as progress reports while the third activity is reported on in this document. For completeness, all three reports are compiled in the following pages.

Progress Report #1
Multiperson Study

Activity Summary

The major objective during this performance period was to collect a set of whole-hand data on a significantly larger population of volunteers than collected during Phase I of this program. This expanded dataset will be used to further develop and refine whole-hand processing algorithms. The larger data set will also provide statistically stronger results. These results will be incorporated into a paper that will be presented and published in the proceedings of the upcoming Biometric Symposium in Baltimore, MD.

Forty additional volunteers were recruited and measured with the prototype whole-hand imaging system using the same protocol as used for the 10 volunteers that made up the original dataset. Specifically, each volunteer made two measurement visits separated by at least one day. During each visit, each of the volunteer's hands was measured three times. When the data from the 40 new people were combined with the earlier 10, the resulting dataset contained a total of 600 measurements of 100 unique hands. The full data set comprised data taken on 21 females and 29 males. The age range of the volunteers was 24 – 70 years old. The volunteers were of mixed ethnicities and demographic profiles.

Goals for Next Performance Period

- Use the new 50-person dataset to develop a fully automated means of segmenting the hand, and localizing and naming the fingertips.
- Reprocess the 50-person dataset in the manner performed previously with the smaller 10-person dataset but incorporating the automated localization technique.
- Incorporate the new whole-hand multibiometric results into the Biometric Symposium research paper.

Progress Report #2
Fingerprint Localization

Fingerprint localization algorithm utilized a segmented whole-hand image; hence, image regions corresponding to the hand pixels (foreground) and remaining ones (background) should be labeled accordingly. Further, in order to decrease computational requirements, segmentation algorithm operated on the "Red" Bayer planes, which has half the resolution (250 DPI) of the final gray-scale image (500 DPI) which is sufficient for segmentation.

Firstly, each one of the associated five direct-illumination raw images is segmented using Otsu binary thresholding method. Then, these binary images are combined into a single, overall segmentation mask using the OR rule: if any pixel belongs to foreground area in any one of the 5 binary images, it is labeled as foreground in the combined segmentation mask (Figure 1).

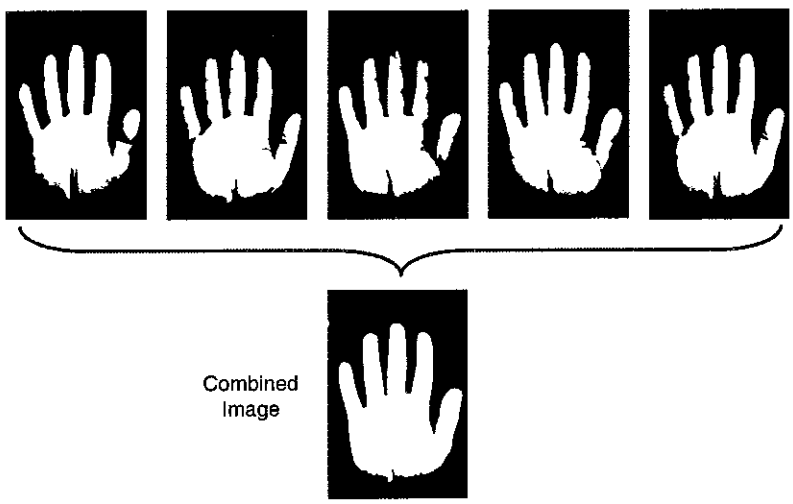

Figure 1. Segmentation of the five individual raw images (upper row) and the resulting combined segmentation map (lower row).

Secondly, binary noise filtering (based on dilation, hole-filling, and speckle removal) is applied to the combined segmentation mask in order to increase its robustness. Further, bottom of the hand is eliminated from the segmentation mask as it does not provide any information for the localization of the fingerprints. Then, the perimeter of the resulting mask is found. After downsampling the list of points on the perimeter to decrease computational time, the curvature values for the points are calculated using the cosine of angles spanned by a point and its neighbors in this downsampled list. During the aforementioned calculation, curvatures corresponding to sections between the bases of any two neighbor fingers are marked with a "–1" value (Figure 2) in order to eliminate them from further consideration, as we aim to find the points with 5 maximal curvatures corresponding to each one of 5 fingertips in the whole-hand image.

Thirdly, points with relatively high curvature values (greater than 0.6) are identified as candidate maximum curvature points. Then, fingertips are localized as local maxima in

the resulting set of candidates. Finally, the resulting (x,y) coordinates are used to locate a fixed-sized rectangular region (640x468 pixels) around the fingertips to localize the 5 fingerprints as shown in Figure 3. Note that after localizing the fingerprints, the fingerprint images are extracted from the 500 DPI gray scale image, and not from the 250 DPI "Red" Bayer plane which was utilized till that step. This ensures the required 500 DPI resolution for post-processing of fingerprints.

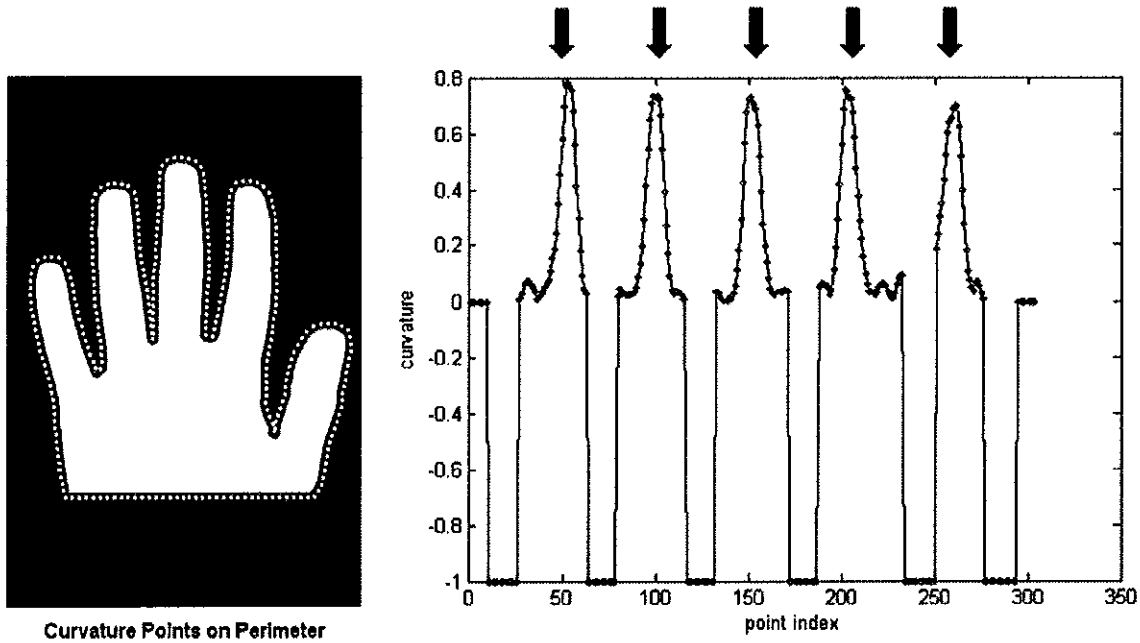

Figure 2. Perimeter points for which curvatures are calculated and plot of curvature values with local maxima highlighted.

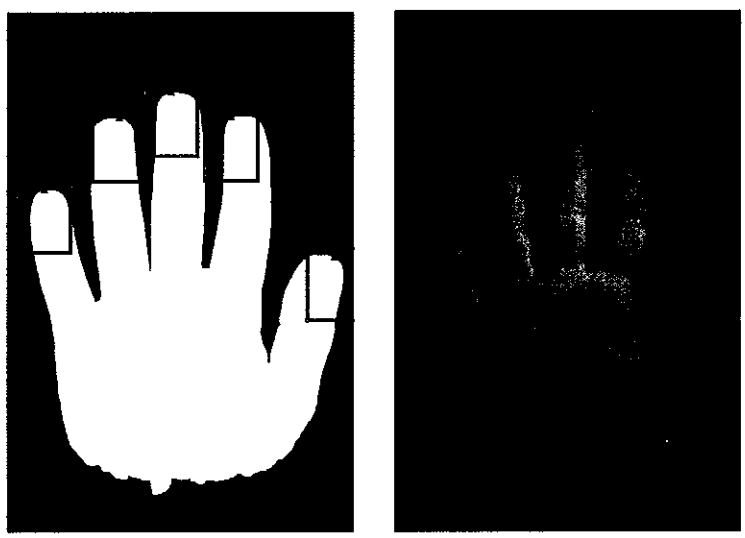

Figure 3. Fingerprints localized on the segmentation map and on the gray scale image.

Progress Report #3
Whole-Hand Composite Image Generation

The developed whole-hand data acquisition device captures 5 multispectral images (MSI) and a single TIR (total-internal-reflection) image per hand (Figure 4). As shown under a different program for fingerprints, combining these distinct information sources via Lumidigm's proprietary wavelet-based MSI algorithm has many advantages, including superior image quality.

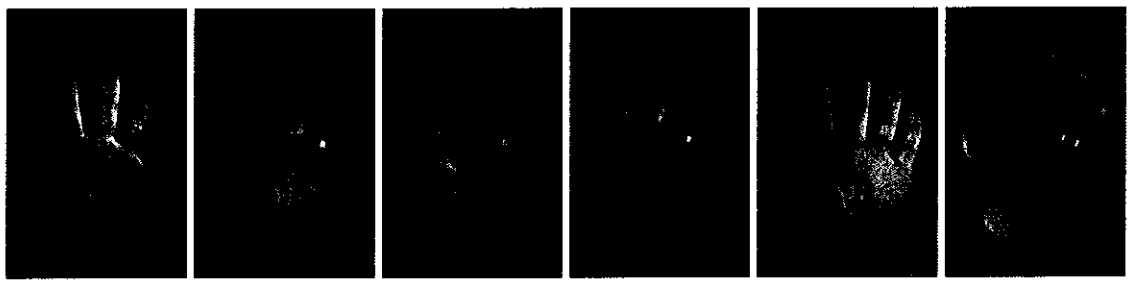

Figure 4. Individual image planes (Five MSI and one TIR) after color balancing.

Direct application of this fingerprint-oriented algorithm to the full image stack (i.e. totally 6 planes, 4560x3048 pixels each) is not feasible due to increased processing power and memory requirements. As a result, an algorithm that processes smaller sized blocks of the MSI stack and then combines the individual outputs into the final output image is developed.

Firstly, in order to increase consistency among neighbor blocks so as to decrease possible blocking-artifacts in the final output image, several parameters -including smoothing related ones- of the original algorithm have been modified. Further, a fixed reference plane (among 6 planes in the stack) is selected instead of the original algorithm's variable one. This ensures that all the individual blocks use the same reference plane for processing. Thirdly, the mask utilization routine is modified so *all* the foreground regions indicated in the mask (corresponding to hand pixels) is used during MSI processing, rather than the *single largest* region.

Finally, an overlapped block processing is applied to the whole-hand data. Figure 5 depicts this overlapping geometry. Basically, 400x400 blocks with 200 pixel overlaps in all directions constitute the elements that are input to the MSI processing. The final output image (size: 4560x3048 pixels) corresponding to the image stack in Figure 4 is shown in Figure 5.

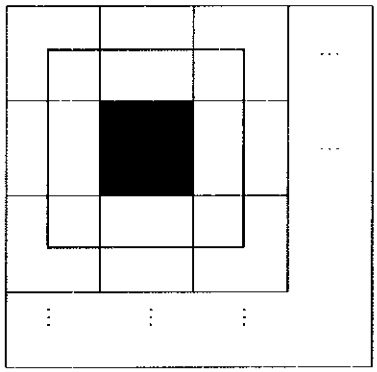

Figure 5. Overlapped block geometry.

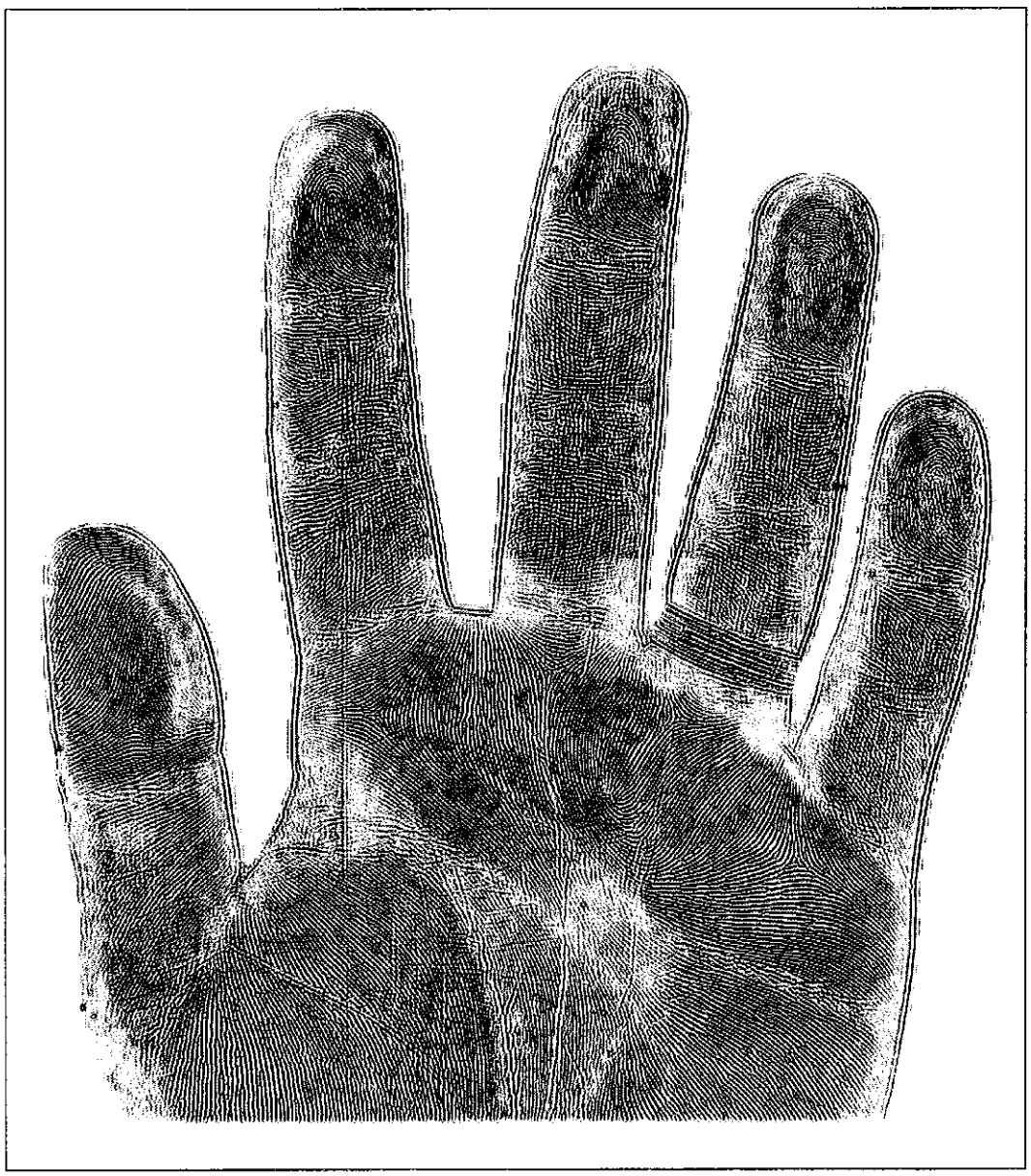

Figure 6. Final output image after overlapped block processing.